Rhythm Detection and Production: Relations with Phonological Awareness Skill at School-Entry

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Child and Youth Studies

Submitted in partial fulfillment

of the requirements for the degree of

Masters of Arts

Faculty of Social Sciences, Brock University

St. Catharines, Ontario

Abstract

Perception of differences in rhythm pairs and ability to tap in time to a beat: significant relations to phonological awareness in children.

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Brock University, 2017

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The present study examines the connection between phonological awareness and rhythm perception and processing in early school aged children who score low on tests for phonological awareness for the purpose of providing further evidence of the connection between rhythm processing and specific learning disorders related to reading. A sample of grade one students from New Haven Connecticut with a mean age of 6 years, were examined for their perception and tapping performance of rhythm using two tasks; the first task examined rhythm perception in phonologically impaired children using a series of audio cue pairs that varied in beats per bar, notes per bar, note frequency, meter, the presence of a crocheted note and duration. Results indicated that participants with low scores on phonological awareness performed poorly when compared to the control group in cases where the audio pairs had fewer beats per bar, notes per bar and when the rhythm pair did not contain a quarter note. Results of this tasks suggest that less complex audio cues that contain fewer changes in rhythm were harder for phonologically impaired children to differentiate between. When performing on the second task participants were asked to tap their finger in time to an audio cue using a tablet. Performance was examined during four phases where changes were made to either the presence of the audio cue or pace of the rhythm. Results indicated that changes to rates of tapping (either slower or faster), and predicting the rate of tapping when there is no audio cue are all impacted by the presence of a phonological impairment. These results support previous studies which have highlighted the

relationship between rhythm tapping performance and delays in reading whereby children who struggle with reading also seem to struggle to keep in time to a rhythmic audio cue. Overall this study continues to support evidence of a relationship between the neural processing of rhythm in conjunction with phonological awareness and reading challenges.

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Introduction

As children progress through school, the capacity to read and learn through reading becomes an integral part of how they are successful academically, often leaving children who struggle with reading behind to continue with challenges and failure in school (Goswami, 2011) It seems to be well documented that children who struggle with reading in their early school years will continue to experience reading challenges and lack of academic success as a result of these problems (Thomson, Fryer, Maltby, et al., 2006)**.** Therefore, it is important to examine the underlying causes of these types of reading difficulties, in order to better understand what is going on neurologically for poor readers, so that supports and interventions can be established to minimize the impact reading challenges have on students' school success.

Currently, language and phonology have provided a clear and significant reciprocal relationship to reading. Phonological processing in pre-readers has been shown to predict later reading success (Bradley & Bryant, 1983). With this understanding established, there is value in examining further how the deficit in phonological awareness is actually occurring in lower order neural functioning. New research has presented the idea that overall rhythm perception may explain how a person begins to segment phonemes in speech sounds that they hear (Seidenberg, 2014). In this study the aim was to further explore this relationship, by determining if rhythm perception and reproduction tasks show a significant relationship to phonological awareness. By improving our understanding of this relationship future research can be done on the implications that rhythm perception or rhythm intervention my have on early intervention or improve the overall ability to detect reading delays at an earlier age.

Connecting Reading Disabilities with Rhythm Production and Perception

Current working definitions of Dyslexia highlight the disorder as specific to one's ability to read and write, despite having a normal to above average IQ (Thomson, Fryer, Maltby et al., 2006). Historically the term "Dyslexia" was first used as by Dr. Rudolf Berlin to label groups of adults who struggled interpreting written text. His intention was to combine "dys", Latin for faulty or impaired with "lexis" which originates from Greek for speech, as a clinical label for the "word blindness" that was typically used to categorize poor readers at the time (Richardson, 1976). With that new classification, identifying those who struggled with reading as "Dyslexic" become common practice, with the first clinically diagnosed case of Dyslexia being reported in the British Medical Journal in 1896 (Pringle-Morgan, 1896). Although, the first descriptions of adults with reading challenges centred around the idea that these reading challenges were associated with a type of visual blindness, it became apparent over time that lack of vision could not accurately represent what had happened to people who were challenged by reading written text (North, 1992).

In 1925 Dr. Samuel Orton first proposed the idea of a deeper neurological connection to reading challenges. He suggested that rather than a vision related deficit, there was disconnect occurring neurologically when the reader is processing text, which prompted primary research into the neurological origins of poor reading (North, 1992). What Orton concluded was that a singular part of the brain's anatomy must be responsible for the deficit dyslexics had with reading. This new insight helped to drive research away from visual impairment as a cause for reading delays towards the more current understanding that the origins of reading challenges start in the brain (Bishop-Liebler, Welch, Huss, et al., 2014).

Just as with the origins of the naming of Dyslexia, the comprehension of how the disorder manifests within the brain took time, and research to shift the understanding of how to represent those people that struggle with reading challenges. Currently, there is much debate over whether the term Dyslexia should be used (Elliot & Grigorenko, 2014). The definition has consistently operated as a catchall for all children who have experienced reading difficulties. This difference in opinion is unpacked in Elliot and Grigorenko's book *The Dsylexia Debate* (2014). The authors argue that dyslexia, although being commonly used as a universal term to diagnose poor readers, only truly should be used to diagnose a specific reading disorder where IQ is not impacted by the individual's problems with phonological processing. The consensus in research suggests that across languages, Dyslexia is related to a specific problem with phonological awareness that does not impact a person's overall intelligence score (Thomson, Fryer, Maltby et al., 2006). Within the brain, Dyslexia as categorized, truly represents a disconnect in relation to a phonological processing deficit which is manifested as challenges with reading (Zeigler & Goswami, 2005). As previously stated this deficit does not seem to impact intelligence, but over time researchers have begun to consider learning and reading deficits as not always singular and exclusive (Zeigler & Goswami, 2005). Through this understanding, new considerations have been made when diagnosing and labeling people who struggle with learning and reading.

As of October 2015, the American Psychological Association dropped the diagnosis of Dyslexia in their new edition of the *Diagnostic Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; American Psychological Association, 2013) in order to be more inclusive of a variety of reading disabilities. Dyslexia itself is no longer used to represent all poor readers, but the diagnosis is still retained to represent a select few individuals who meet the necessary criteria for diagnosis (Bishop-Liebler, Welch, Huss, et al., 2014). New standards have taken into consideration the variety of learning challenges which manifest with people struggling to read. The new standard for diagnosing people who perpetually struggle to read, or have difficulty with other academic skills, such as writing and arithmetic, is to categorize those individuals as having a Specific Learning Disorder (American Psychological Association, 2013).

This movement away from categorizing all delays in reading, and reading challenges, as Dyslexia has supported a more inclusive approach to diagnosis and treatment of reading problems. In this new framework, Dyslexia becomes only one of many specific learning disorders that may be used to categorize individuals who struggle to phonologically process and therefore lack the ability to learn from written text. The new understanding of Specific Learning Disorders also puts an emphasis on increasing the diagnosis of reading challenges at an earlier age, so children who are struggling to read can access necessary supports which will then serve as a safety net for learning as they move through their schooling. In this study, the discussion regarding poor readers was explained using the current working definition of reading difficulties provided in the *DSM-5* (American Psychological Association, 2013). The population of participants was drawn from a category of poor phonological processors, rather than students who had been diagnosed with specific learning disorders, as this working definition was only just emerging as consistent language in diagnosis.

The goal of this research project was to determine if music differentiation, and rhythm production tasks can be used as predictors for later reading delays, and/or, any specific learning disorders related to reading. As stated previously, the general understanding of specific learning disorders in reading manifests from problems within the brain’s capacity to interpret phonemes, and, more specifically, with readers having had problems differentiating between syllables, and segmenting sounds; these delays can be understood as a general problem in phonological awareness (Muneaux, Zeigler, Truc, et al., 2004). Phonological awareness, serves as the ability to recognize, differentiate and manipulate sound units in words (Boet, Wouters, van Wieringen, et al., 2005). The disruption in this process leads to difficulty in processing phonemes, differentiating syllable boundaries in speech, reading and reading comprehension (Leong & Goswami. 2014). More specifically, this barrier in phonological processing has been identified as an impairment in a child's ability to detect the change in the sound's amplitude envelope between syllables; this change indicates an important acoustic cue to the rhythmic timing of speech (Dellatolas, Watier, Le Normand, et al., 2009), and suggests the capacity for a connection between audio stimuli and reading development

When fMRI data was analyzed, results for reading impaired participants demonstrated how different their brains operated in comparison to average and above average readers (Bishop-Liebler, Welch, et al., 2014). The average fMRI scan for a typically developed reader shows that there is bilateral movement across the brain's hemispheres during reading tasks. More specifically this activation involved the primary visual processing centres, and included the temporal gyrus, Wernicke's area, and the angular gyrus (Horwitz, Rumsey & Donohue, 1998). This trend in activation in the posterior regions has been well documented within literature supporting the neural understanding of reading (Shaywitz, Shaywitz, Pugh, et al., 1998; Pugh, Mencl, Shaywitz, et al, 2000; Habib, 2000; Shaywitz, Shaywitz, Pugh, et al., 2002). In poor readers there was a variation in this activation: the right hemisphere responded similarly while performing reading tasks, but the disconnect happened with the processing across the left hemisphere, where scans displayed a lack of activation in the angular gyrus and posterior regions (Shaywitz, Shaywitz, Pugh, et al., 2002).

This processing deficit depicted through fMRI is an indicator of how Specific Learning Disorders manifest within the brains of poor readers, but, there is a difficulty associated with understanding such a complex neurological processing problem, it only represents a portion of what is going on inside poor reader's brains.

As stated, with the lack of cross hemispherical processing from poor readers, research into specific learning disorders has highlighted on the neurological level, how poor reading operates in the brain. More specifically new ideas into what is going on for poor readers, that is resulting in the lack of activation in the reading centres of the brain (Boet, Wouters, van Wieringe, etal., 2005).

Given that reading is a learned skill which occurs in a developmental progression over the early part of the human lifespan, the origins of the skills necessary for the mastery of reading begin to occur in early childhood. Research into the beginning of these skills suggests the importance of an auditory connection in the development of reading where the ability to interpret speech, and, specifically, speech sounds and the capacity to segment sounds, appear to be impaired for poor readers (Woodruff Carr, White-Schwoch, Tierney, et al., 2014).

Interestingly, this rhythmic pattern of sound in speech is almost identical to the sounds and rhythm patterns seen in music, where the attack time of a note played on an instrument is interpreted by the brain in the same way as rhythmic patterns in speech (Bishop-Liebler, Welch, Huss et al., 2014). There is some variance in complexity between speech interpretation and music, specifically in some asymmetrical hemispherical interpretations (Tervaniemi & Hugdahl, 2003) but the key similarities come from the cross hemispherical processing between the left and right side of the brain, as well as the primary occurrence of processing happening more asymmetrically within the brain's left hemisphere (Yuskaitis, Parviz, Loui, et al., 2015); this specific connection in processing similarities and its parallels with what is already understood from research into the neurology of Specific Learning Disorders, that suggests how music is processed by the brain and how the brain processes phonemes in speech and reading indicate the capacity for which music can be used to support the identification of reading challenges (Overy, Nicolson, Fawcett, Clarke, 2003).

Currently, this neuro connection between speech and music has already been well documented in experimental literature (e.g. Thomson, Fryer, Maltby et al., 2006; Muneaux, Ziegler, Truc et al., 2004; Overy, Roderick, Nicolson, et al., 2003). In more recent research connections are being made regarding how rhythm production and musical meter differentiation can be utilized to identify reading delays before a child has a mastery of reading (Thomson & Goswami, 2008).

Rhythm, Phonology, and Auditory Neuroscience

The challenges faced by children who develop Specific Learning Disorders related to reading challenges, can really be understood at the neurological level. Research into how reading and music are neurologically interpreted by children has identified a common area within the brain, where the majority of sound interpretation occurs (Tervaniemi, Kujala, Virtanen, et al., 1999; Abrams, Nicol, Zecker, et al., 2009) . Both music and language sounds are interpreted in the brain's auditory processing centres, more specifically, sound interpretation happens across the right and left hemisphere of the brain through the primary auditory cortex (Abrams, Nicol, Zecker, et al., 2009). The role of the auditory cortex is to examine tonality and sound segmentation in both music and language (Tervaniemi, Kujala, Virtanen, et al., 1999). In a study conducted by Zatorre, Belin and Penhune (2002) the authors examined the structure and function of the auditory cortex in relation to music and speech interpretation. They highlighted that a unifying factor in processing, both speech and musical stimuli, is that there was a cross hemispherical interaction in the auditory cortex between the right and the left side of the brain with the majority of auditory processing occurring within the left hemisphere. Similar results indicating this unifying processing factor have also been identified in other studies (Celsis, Boulanouar, Doyon, et al.,1999; Tervaniemi & Hugdahl, 2003; Rauschecker & Scott, 2009;).The value of this previous research is that it is consistent with research findings examining poor readers and neural processing, where studies examining the neurological performance of poor readers consistently found a problem with left hemispherical processing- the key area for auditory processing in general (Shaywitz, Shaywitz, Pugh, et al., 2002)

This left hemispherical deficit for poor readers, and the linkage this hemispherical disconnect has with the neural structures required for the development of successful reading, indicate the value of examining how auditory stimuli interpretation is related to phonological processing. Interestingly, this activation pattern includes auditory stimuli of all kinds, and specifically, when examining brain activation while listening to music, similar left hemispherical centres are activated (Platel, Price, Baron, et al., 1997) In a study conducted by Platel, Price, Baron, et al. (1997) the author discovered that the neural structures involved in music perception, highlighted left hemispherical activation in their brain, specifically when reviewing rhythm based tasks, they noted activation in the Broca’s area, which is commonly associated with speech processing was being activated when interpreting music like sounds. Other literature noted this activation similarity in music as well, highlighting the left hemispheres involvement in the perception of neural processing in music (Meister, Krings, Foltys, et al., 2004; Maess, Koelsch, Gunter, et al., 2001; Patel, 2010; Patel, 2003; Peretz & Zatorre, 2005). Noting these similarities in the literature is important in understanding how language perception and reading can be connected to the brain's capacity to process music, and particularly the elements of music, such as pitch and rhythm.

Neural Anatomical Differences in Rhythm Perception

The neural anatomy discussed above highlights the complexity by which audio stimuli of any kind is processed by the brain, but each component of systemic sound sequences highlights a more complex neural system at play, when processing particular sound elements; this specifically is the case for rhythm interpretation (Goswami, 2010). Currently the academic community, who is focusing on reading and the role of rhythmic processing in the brain collectively, does not define the specific elements of rhythm, but, in contrast, the research in the academic music community has highlighted the specific elements that need to exist in order for a collection of notes or sounds to be defined as 'rhythmic'. Thaut, Trimarchi and Parsons (2014) highlight these three key elements in their study on musical rhythm perception in the brain. The authors in this case referenced that research in the academic music community considers something to be a rhythm when it first contains some unit of timing whereby there are purposeful on and off periods when a sound is produced. Secondly, timing of sound units must be in groupings, not happening sporadically, but grouped together as a unit. The third element of rhythm highlights the pace at which the on and off sound units occur, highlighting the tempo of a musical sound sequence.

What is interesting about these three distinct elements, is the role they play in rhythm interpretation within the brain. Although, when listening and distinguishing a rhythm, it may appear that the stimuli itself could be interpreted as one whole until, by the previously mentioned auditory cortex, the brain distinguishes these three different aspects of rhythm and uniquely processes them in different neurological centres; one of these centres is the cerebellum (Forgeard, Gottfried, Schlaug, et al., 2008).

Uniquely, the cerebellum serves as a structure for the delivery of rhythmic timing units to the proper brain structures used in processing distinct types of rhythmic stimuli, and this happens in specific areas of the cerebellum. This occurs in the cerebellum in cases of rhythmic perception and production in speech, and musical rhythm patterns (Penhune, Zatore & Evans, 1998). Penhune, Zatore and Evans (1998) highlighted in their study that the perception of rhythm unfolds in the cerebellum in three ways: first, is the role it plays in distinguishing timing operations in external rhythmic stimuli. Although not totally apparent, during Positron Emission Tomography (PET) scans participants showed activation in their cerebellum when interpreting the timing of audio stimuli. Secondly, it was apparent that the segmentation of the auditory signal occurred within the cerebellum, exhibiting that this area serves as the gateway through which the processing of auditory stimuli occurs. With these two processes being apparently connected to the cerebellum Penhune, Zatore and Evans concluded that, based on the activation they noted within the brain during the presence of audio stimuli, the cerebellum did not just serve as a timing operator for audio stimuli, but functions as a cross modal binder to support the complex interpretation of any rhythmic stimuli. Highlighting the final way, the cerebellum is responsible for the perception of rhythm. Other authors have also highlighted these three operations of the cerebellum in relation to rhythm in their research (Parsons & Thaut, 2001; De Smet, Paquier, Verhoeven, et al., 2013; Thaut, Trimarchi & Parsons, 2014).

Additionally, the basal ganglia serves a role in the neural network associated with processing rhythmic auditory stimuli; where PET scans have noted, again, the role this location has in comprehending explicit rhythmic timing (Thaut, Trimarchi, & Parsons, 2014). Supporting the overall complex neural structure associated with the processing of auditory stimuli, research has determined that the location of where timing comprehension occurs is not central to just the cerebellum alone.

What is important about understanding these neural pathways within the cerebellum and basal ganglia structures, is that they help to connect and grow hypothesis for the relationship between processing music and phonology, specifically, the rhythmic and time structure associated with both processing the phonological components of speech and the beat structures of music.

Although the cerebellum has been linked consistently to its specific role in human motor function (Doyon, Song, Karni, et al., 2002). New ideas and research into the cerebellum's more complex association with higher level processing and functioning has began to emerge (Thaut, Stephan, Wunderlich, 2009; Marien, Ackerman, Adamasek, 2014; Thaut, Trimarchi, & Parsons, 2014). For the purpose of this study, focusing on the cerebellum's role in phonology is important to reiterate that within the brain there are processing centres responsible for the comprehension of musical stimulus and phonological speech components. Setting up potential for a connection to be made in rhythm tasks and phonological awareness.

In a consensus paper written by scholars, which focuses on the higher order of the cerebellum, Marien, Ackermann & Adamaszek, et al. (2014) note the unique role that the cerebellum has in processing the rhythm and timing of speech. The authors note that specifically the handling of the phonetic timing is occurring partially within the cerebellum. Noting that this aspect of phonetic timing, and neural activation, occurs as part of the initial stages of speech processing, before signals are interpreted within the auditory cortex, which is more commonly associated with auditory processing.

Beyond just the timing role that these mechanisms play in the perception of rhythmic auditory stimuli in speech, the cerebellum also has the responsibility of processing the rhythmic timing of music. Thaut, Trimarchi, & Parsons (2014) noted in their study on neural rhythmic processing that blood flow increased in the right posterior cerebral areas when participants were dealing with tasks related to tempo and musical meter. Notably, studies independently have considered the workings of the cerebellum in rhythmic timing both in phonology (Leggio, Silveri, & Petrosini, 2000; Nicolson, Fawcett & Dean, 2001; Nicolson & Fawcett, 2006) and musical tempo and meter (Penhune, Zatorre & Evans 1998; Chen, Penhune & Zatorre, 2008; Chen, Penhune & Zatorre, 2008; Thaut, Stephan, Wunderlich, 2009). With literature in both these areas focusing on the connection of rhythm, both in the processing of phonology and music. It begins to paint a picture of how music, and specifically the rhythmic components of music can be used to determine problems when processing the rhythmic phonology of speech. With the consistent support from literature, that suggests phonological awareness is related to later reading performance, it could be plausible that deficits in rhythmic processing may be what causes this performance disconnect in poor readers.

Connections Between Rhythm and Phonological Awareness

Currently, many researchers have identified this connection between the similar neural processing centres role in both language (Nagarajan, Mahncke, Salz, et al., 1999; Zatorre, Belin & Penhune, 2002; Banai, Hornickel, Skoe, et al., 2009) and rhythm interpretation (Pantev, Oostenveld, Engelien, et al., 1998; Schneider, Scherg, Dosch, et al., 2002; Brattico, Tervaniemi, Näätänen et al., 2006;), and, as a result, it is plausible to understand that disruptions in phonological awareness in language and reading would also result in disruptions in music and rhythm comprehension. As previously mentioned, these processing similarities, have led to research that focuses on the role musical and rhythmic processing can have in reading comprehension and this connection can be seen in studies that have examined the relationship between poor readers and their ability to interpret rhythm (Brattico, Tervaniemi, Näätänen et al., 2006;).

Research examining these relationships have noted that poor readers also seem to struggle with, dancing, playing an instrument and other rhythm reproduction and perception based skills (Nicolson, Fawcett, & Dean 2001; Forgeard, Schlaug, Norton, et al., 2008; Huss, Verney, Forsker, et al., 2011;). Specifically, Huss, Verbey, Fosker, et al. (2011) suggest that the results of their study may indicate that the learning of rhythmic co-ordination activities like singing and dancing may have unsuspected benefits on language development. With the plausible connection between rhythm and language development identified within the established literature, there is room to expand the current understanding of this relationship.

Currently, research into the area of rhythm production and differentiation in relation to reading and phonological processing, has indicated common themes in results across a variety of studies (Marshall, Snowling, Bailey, 2001; Ramus, Rosen, Dakin, et al., 2003; Boets, Wanters, Wieringen, et al., 2008). Consistent results indicate that there is a connection between acoustic processing and reading which has led to the creation of the rapid temporal processing theory (Benasich & Tallal, 1996). This theory suggests that a deficit exists for persons with specific learning disorders and their ability to discriminate sound frequencies and rhythms. Continuous evidence of this theory has appeared regularly in literature (Marshall, Snowling, Bailey, 2001; Ramus, Rosen, Dakin, et al., 2003; Boets, Wanters, Wieringen, et al., 2008). This unchanging representation in literature, highlighting rapid auditory and phonological processing as a major deficit for individuals with Specific Learning Disorders, has resulted in more specific research into how this deficit occurs.

Primarily, research has detailed that there seems to be identifiable impairments regarding a dyslexic child's ability to detect the envelope onset of a sound. For example, in a study conducted by Goswami, Thomson, Richardson, et al. (2002) the authors noted that there was a significant difference in how children with reading impairments detect the onset of the sound envelope, where by the test group of poor readers underperformed on tasks where they were to detect beats and sound onset.

This onset of sound is called the rise time, and in music this is represented as the highest pitch of an individual note or sound. In language, this same sound principle occurs in segmented syllable sounds in speech, (Huss, Verney, Fosker, et al., 2011). Just like in a musical note, the primary auditory cortex of the brain interprets the highest frequency of a syllable's sound in the same way, and as noted earlier activation of the left hemisphere of the brain occurs specifically when processing rhythm.

The relationship between the rise time detection and Specific Learning Disorders has been well documented (e.g. Thomson, Goswami & Baldeweg, 2009; Beattie & Manis, 2012; Goswami, Fosker, Huss, et al., 2011). Most research examines tasks where a child is asked to decide if two sounds of differing rise time are the same or different. A specific example of this is in a study conducted by Goswami, Huss, Mead, et al., (2013), where the authors examined how children with specific learning disorders differentiated between two musical arrangements with varying rhythmic and note based conditions. Similarly to previous research, the authors noted that poor readers struggled more in differentiating similar sound parings than the control group, adding to the idea that the interpretation of rhythm and rise time, could be the specific link to how music and reading perception are connected in the brain.

Just as rise time is interpreted similarly in the brain between syllabic sound onset and musical rhythm, research has also indicated that a similar connection exists between the auditory temporal processing of speech syllable patterns and the capacity in which readers can copy a rhythm sequence. In the auditory processing of speech, as well as in the auditory processing of music, rhythm is a key indicator of the acoustic cues that segment sound for the listener (Carr, White-Schwoch, Tierney, et al. 2014). In research conducted by Carr, White-Schwoch, Tierney, et al. (2014) major findings concluded that children who could synchronise their tapping to a rhythmic pattern of notes performed better at language skill tasks than children who struggled with synchronising. Similar results were also found across many studies looking into rhythm production and Specific Learning Disorders (Thomson, Leong & Goswami, 2013; Goswami, Huss, Mead, et al., 2013; Suranyi, Csepe, Richardson, et al., 2009; Thomson & Goswami, 2008; Dellatolas, Watier, Le Normand, et al., 2009; Overy, Nicolson, Fawcett, et al, 2003).

Adult Musicians with Specific Learning Disorders

Beyond the existing literature demonstrating specific examining connections to between musical meter interpretation and phonological processing, more connections and inferences into this relationship can be derived from research into musicians who have Specific Learning Disorders. This research examined the reading skills of musicians to determine if the authors could grow the understanding of the relationship between reading and music, by flipping most traditional research, as stated earlier, that only focuses on reading's relationship to music and not the other way around (Bishop-Liebler, Welch, Huss, et al., 2014).

The "Dyslexic Musician" presents an interesting enigma to research into the correlation between Specific Learning Disorders and musical meter interpretation. Some notable musical figures who are self proclaimed "poor readers" include Black Sabbath lead singer Ozzy Ozborne, Oasis front man Nole Gallagher, and Beatles founding member Johan Lennon (Hickman, Richard, & Brens, 2014).

Reading delayed musician’s abilities to interpret musical notation and rhythmic patterns suggests that the workings of Specific Learning Disorders in the brain, may highlight a more complex relationship between auditory processing abilities, and reading. Otherwise, how is it possible that such high functioning musical talents claim to also have established delays in reading?

In a study done conducted by Weiss, Granot & Ahissar (2014), the authors specifically looked into the auditory processing and working memory of adult musicians who self reported as having reading delays. What they found was that, consistently, the reading delayed musicians who participated still struggled with their working memory of auditory sounds, rhythm and melody similarly to patterns in non-musician poor readers.

Interestingly though, Weiss (et al, 2014) also noticed that the musicians, who reported as having reading problems, performed marginally better on reading tasks compared to their non musical counterparts. So although their reading skills were not as high as normally functioning readers, they performed better than the group of general, non-musical, poor readers, supporting the idea that persistent engagement with music over the course of childhood into adulthood could help mediate the impacts of the auditory processing delays that come with having a Specific Learning Disorder, as a way to offset poor reading performance.

Musical Entrainment as a Mediator for Reading Delays

Findings in research related to adult musicians with learning delays, can also be supported by research into neurological plasticity (Herholz & Zatorre, 2012; Bosnyak, Eaton, & Roberts, 2004). Results in this area of study suggest that rigorous musical training can support a level of brain plasticity which can mediate the impact of Specific Learning Disorder has on phonological processing. Herholz and Zatorre (2012) specifically examined current research regarding the brain plasticity induced by musical training and through referencing Bosnyak, Eaton and Roberts (2004); Menning, Roberts and Pantev (2000); Schulte, Knief, Seither-Preisler, et al. (2002) the authors highlighted that a level of training, specific to speech sounds interpretation, shows that musical training specifically helped improve the behavioural response to auditory stimuli in children with reading delays.

More specifically, the authors highlight that within the literature on musical training and plasticity, there is even greater impact demonstrated when musical intervention and training is given at an early age. Research by Kraus and Chandrasekaran (2010); Baharloo, Johnston, Service, et al. (1998) both found that age was a major determining factor in musical training’s ability to mediate scores on auditory-related tasks and processing. Both studies examined the fMRI outputs of children who received intensive musical training and compared their scans to adults who received training later in life, what was found was that as age increased the auditory cortex’s and left hemispherical capacity for plasticity decreased, suggesting that earlier musical training had a greater impact on an individual’s capacity to process phonological information within the auditory cortex.

A current surge of studies investigating musical training and its impact on phonological awareness (Patel, 2011; Slater, Skoe, Strait, et al., 2015; Habibi, Cahn, Damasio, et al., 2016;

Kempert, Gotz, Blatter, et al., 2016) has increased the need for research into the relationship between rhythm processing in music, and phonological awareness as a way to support new initiatives into how music and specifically how rhythm based musical tasks can support early identification of Specific Learning Disorders

Most recently, an article by Habib, Lardy, Desiles, et al. (2016), has used the previous research regarding musical training and its relationship to the processing of phonological awareness, as a guide, to highlight musical training as having potential for therapeutic interventions for children struggling with reading. In the results, the authors noted that interventions focusing on the rhythmic features of music, yielded better performance post-intervention, suggesting that the improved rhythmic perception and performance on reading tasks after the intervention supports the idea that the temporal deficit for poor readers can be mediated by musical training that focuses on rhythm. These results, and new research into the relationship between musical training and early interventions, could have interesting implications for diagnosis and educational interventions (Seidenberg, 2013).

Rhythm Production and Perception Tasks

Previous research has examined specific musical tasks, relating to rhythm, as a way to support the idea that the processing of rhythm is what can connect musical interpretation and phonological awareness; this hypothesis was used as a way to explain the neurological deficit that could potentially help to identify Specific Learning Disorders (Huss, Verney, Fosker, et al. 2011; Goswami, Huss, Mead et al., 2013; Thomson, Fryer, Maltby, et al, 2006). Testing this hypothesis in research has come typically in two types of tasks: the first being focused on a participant's perception of rhythm in an audio cue and the second being rhythm reproduction tasks where participants replicate the rhythm of an audio cue through a tapping task.

In tasks related to rhythm perception, typically participants are required to determine the difference between two auditory stimuli that have varying musical conditions such as beat, note number and pitch (Huss, Verney, Fosker, et al., 2011) . It was these types of tasks that helped grow the understanding that rhythm specifically above other auditory conditions could be the phonological connection between music and poor reading.

As previously discussed, it is well documented that there is a phonological connection between how both music and phonemes are interpreted by the brain, but what is coming to light are the specific audio conditions causing the disconnect (Huss, Verney, Fosker, et al., 2011). When studying for perceptions of varying auditory conditions it’s the cases where rhythm conditions varied that often demonstrated the specific challenge that exists for poor readers and their perception (Goswami, Huss, Mead et al., 2013).

In a study conducted by Huss, Verney, Fosker, et al. (2011), the authors noted that in perception tasks looking at rhythm differentiation, poor readers ages eight to thirteen were less successful at identifying differing audio cues when rhythm conditions focused on beat intensity and note sequence. In both the case of intensity and sequence, the study identified that children with specific learning disorders performed more poorly compared to age matched peers when identifying note sequences of two, three and four beats per bar, and also in conditions when there was a musical meter change impacting the onset of the rhythm after long and short note sequences.

Similar results, regarding the rhythm perception of children with reading delays, were also noted in a study done in conjunction with the participants of Huss, Verney, Fosker, et al. (2011) by Goswami, Huss, Mead et al., (2013) which was conducted a year later. In this case more specific considerations were taken on the rhythm conditions, but just as seen by Huss, Verney, Fosker, et al. (2011), with this same group of children, the authors noted similar deficits in rhythm perception tasks. Again, they struggled compared to age-matched controls to differentiate between similar, but different, auditory stimuli where conditions related to rhythm, sound onset and number of beats were concerned. A notable differing condition in this study suggested that the change in note accent also demonstrated an impact on performance; where poor readers where unable to detect a difference in pairs containing this condition in comparison to age-matched controls.

What is interesting about the findings and relationship between these two studies, is the connection to the performance of poor readers when listening to audio pairs where the elements of the rhythm conditions were manipulated. In both cases, authors noted specifically that rhythm, and changes in rhythm, were what impacted performance more so than cases where other auditory conditions were changed, such as pitch or changes in number of notes. Specific manipulated variables in the sound rhythm sequence was what most likely predicted the difference in performance.

Another interesting consideration within these two studies, is that there did seem to be a threshold where performance was no longer impacted by differences in rhythm. Both authors noted that in pairs where there were five-note sequences, performance was not significantly different between poor readers and aged matched controls; this could suggest that in cases where rhythm length or complexity was higher, participants could start to differentiate better than when different rhythm conditions were less complex.

Beyond the significant results highlighted by tasks related to the rhythm perception of poor readers, research also suggested that a second type of rhythm tasks has also showed notable performance differences for poor readers (Thomson, Fryer, Maltby, et al, 2006). Tasks related to the motor reproduction of a rhythm sequence, as performed by poor readers, suggests another processing connection to a rhythm related task (Thomson, Fryer, Maltby, et al, 2006). In tasks where poor readers are asked to listen and copy a rhythm through tapping, both in cases where they could hear the audio cues and in cases they could not, suggest that where there are changes made to the conditions of a rhythm sequence both in pace and presence of an audio cue, poor readers struggle to perceive the changes and tap accordingly to the new condition (Thomson, Fryer, Maltby, et al, 2006).

This specific difference in the tapping performance of poor readers was noted in three separate studies, where all three examined the performance of poor readers in paced and unpaced rhythm conditions (Thomson, Fryer, Maltby, et al, 2006; Thomson and Goswami, 2008; Corriveau and Goswami, 2009). One of the studies was conducted in 2006 by Thomson, Fryer, Maltby, et al. where the authors examined the tapping performance of adults who had been diagnosed with Specific Learning Disorders. In this case, the authors noted a significant difference in tapping performance of adult poor readers in comparison to typical adult readers both in paced and unpaced conditions where the tapping interval rate (ITI) was 1.5 and 2.0 Hrz, noting that differences in performance were only analyzed for the middle fifteen taps. These results suggested a lack of rhythm sensitivity even in adulthood for poor readers.

Like results have been noted in studies where participants are children who have been identified with reading delays (Woodruff Carr, White-Schwoch, Tierny, et al., 2014; Dellatolas, Watier, Le Normand, et al., 2009). Under similar conditions to the previously mentioned study, comparable tapping performance results were identified by Thomson and Goswami (2008) and Corriveau and Goswami (2009). Both authors studied the tapping performance of children, ages seven to eleven, where the fifteen middle taps were analyzed during each phase of the task in paced and unpaced conditions of 1.5, 2 and 2 Hrz. Both authors noted significant differences in tapping performance between poor readers and aged matched controls in cases where conditions changed and varied through the phases of the tapping tasks, noting that the unpaced condition specifically was challenging for all participants and did not produce significant within group differences.

The only notable difference between the results of the two studies was that in the case of Corriveau and Goswami (2009) the authors observed a significant difference in tapping anticipation for poor readers compared to typical aged matched readers, where Thomson and Goswami (2008) recorded no significant differences in anticipation between their control and test groups.

The notable significance of all these studies is the idea that there is not only a rhythm perception deficit for poor readers but this deficit also manifests cross modal between auditory processing and the subsequent motor response, which highlights the previously discussed neural anatomical connection with how the brain processes rhythm, in the motor functional cerebellum, and auditory cortex. The results of the aforementioned studies analyzing both rhythm perception and rhythm production of poor readers support the idea that the rhythm processing centres of the brain may be where the specific rhythm disconnect is occurring in poor readers.

Research and Rationale

With the highlighted neural anatomical connections to rhythm perception, and the link rhythm perception has to poor reading it is important to take these understandings and apply them into similar research regarding how rhythm perception and reproduction can be utilized to identify poor reading. If consistently, in research, poor phonological processing shows to be connected with deficits in rhythm processing in relation to neurological anatomy; the rapid auditory processing theory; the perception of rise time of a sound onset, and the unique enigma of musicians with specific learning disorders, then it is important to support the growing literature on the connection between phonological awareness, reading and rhythm interpretation.

Success in identifying this specific rhythm connection can be used in the future as a way to support early interventions for reading using music and rhythm tasks. Also if there is a unique connection between the inability to successfully process rhythm correctly, this noteworthy factor can be utilized as a way to identify, and potentially disrupt the impact that poor reading can have over the lifespan of an individual. On the grounds this significance, it is valuable to reproduce results of research that has previously highlighted the distinct relationship rhythm has to the perception of both music and speech, through identifying distinct differences in poor readers and their ability to perceive and reproduce rhythm. It is also valuable to identify gaps within this research as a way to provide a more comprehensive idea of when and how this relationship between rhythm perception and production manifests, and the effect that it has on phonological awareness and poor reading.

This current study would hypothesize based on the results of previous studies, that when a child experiences difficulties in interpreting musical rhythm, that they will also experience difficulties in phonological awareness due to the anticipated gaps in both phonological awareness and rapid auditory processing. Also, that there would be notable deficits in rhythm perception in both the cerebellum, basal ganglia and auditory cortex. Based upon this working hypothesis, subjects within this study, who have been identified has having below average scores in phonological awareness were expected to preform poorly on the proposed rhythm differentiation and reproduction tasks.

In order to support this idea, this study examined the relationship between a child's ability to produce rhythm with and without and auditory stimulus over varying rhythm phases, as well as examined a child's ability to differentiate between two different rhythm sequences that vary in rhythm conditions. As alluded to previously, the purpose of this research is to add to the body of knowledge that suggests there is a correlation between musical rhythm processing, rhythm differentiation, and phonological awareness in early readers.

Where this study differed, in comparison to existing research, is that it attempted to fill the gaps of knowledge both related to age and certain conditions. In the case of both the rhythm production task, and the rhythm perception task, participants of this study were younger than the traditional age of population previously studied. This study sought to examine if similar results in rhythm production and perception could be identified in pre reading children, as a way to highlight the use of rhythm tasks to identify the potential for specific learning disorders at an age were reading intervention can be provided before there is significant learning impact for children over the course of their school aged years.

Also in the case of rhythm reproduction tasks this study included an additional specific rhythm condition where the paced variable returned to the participant, after it had been removed, to test the capacity participants had shifting their tapping back to the previously heard rhythm condition.

Research Questions

In relation to the rational concerning that value of examining the relationship between a child's interpretation of rhythm and phonological awareness, this study examined the following research questions.

1. Do existing methodologies, that test for rhythm perception and production, yield similar results in grade one participants at school entry?
2. Does scoring low on standardized tests for phonological awareness identify a relationship to poor performance on rhythm tasks?
3. Are there specific rhythm variables within audio stimuli that result in poor task performance in participants who are phonologically impaired?
4. Can grade ones maintain a rhythm through finger tapping through task phases that manipulate tapping rate, the removal of an audio cue, and the return of the audio cue?

With the research questions highlighted above, results of the experiment are expected to demonstrate a significant relationship between rhythm task performance, and phonological awareness. Specifically, this study anticipated that unique rhythm related variables would stand out over non rhythm variables, as what impacts performance on the rhythm tasks, for children who scored low on phonological awareness. Also, this study anticipated that since research has established a reciprocal relationship between phonological awareness and later reading ability in early school aged children, that just as poor reading scores have demonstrated poor rhythm task performance, low phonological awareness will also predict poor rhythm task performance. Finally, by replicating existing methodologies that have successfully shown a significant relationship between reading and rhythm task performance, this investigation expected to see results that suggests a significant relationship between phonological awareness and rhythm.

Methods

Participants

This research tested a population of first graders in New Haven Connecticut. The participants of this experiment were taking part in a longitudinal study exploring the genetic markers for dyslexia. Collaborations with Yale University allowed this study to access participants for the purpose of researching connections between rhythm perception, rhythm reproduction, and Specific Learning Disorders.

800 students, with a mean age of 6 years, participated in the overall longitudinal study on Dyslexia. For participants to be included within this study, and as well as the longitudinal study they had to have been attending one of three New Haven schools that agreed to administer the Reading Recovery and EMPOWER/PHAST reading interventions. Participants were recruited as part of the longitudinal study were grouped into 4 cohorts, Questionnaire, Assessment, Intervention and Intervention-PHAST. For the purpose of this study only children who participated in the Assessment cohort completed the tasks.

Children who were excluded from the current and longitudinal research had either missed more than 20 days of school in kindergarten, spoke English as a second language, been identified as wards of the state or had a previously diagnosed developmental delay.

With the parallels between this study and existing research, the analysis of this study's results aimed to utilize existing frameworks within similar research to help support the design of the rhythm tasks so that the results of this current study served as a basis for comparison within the results. (Huss, Verney, Fosker, et al., 2011; Corriveau & Goswami, 2009; Thomson & Goswami, 2008; Goswami, Huss, Mead, et al., 2013;) For the purpose of analysis, the participants in this study had been divided into two categories, phonologically impaired, or not phonologically impaired.

Inclusion in this study required participants to complete the pre-assessment phonological processing test, along with either, or both, of the rhythm reproduction task and rhythm perception task. The means and standard deviations of both the phonologically impaired (PI) students were compared to the control group of Non Phonologically Impaired (NPI) participants. Both groups received the Comprehensive Test of Phonological Processing (CTOPP) to determine phonological awareness. Participants who scored less than or equal to 85.00 were considered to have an impairment with phonological processing (PI). Participants that scored above 85.00 were considered to have no phonological impairment and made up the not phonologically impaired control group (NPI) (see Table 1). Each task had varied rates of participants as a result of which rhythm task was completed, but inclusion in the rhythm production and entrainment tasks was selected based on the above criteria, and overall difference in participants was due to the tasks being analyzed separately in the overall sample of the longitudinal study. Due to the participants in this study having been a part of a larger research project into the origins of Specific Learning Disorders, many test and outcomes were analyzed. For the purpose of this study, only the variables relevant to the results of this project were used for analysis of the overall participant scores on the rhythm entrainment task and rhythm differentiation task.

For participants included in the sample for both tasks the average age of participants was 6 years old (SD=0.51) ranging from 5 to 7 years, at the time of study (see Table 1). The overall sample had a mean phonological awareness score of 85.12 (SD=16.22) on the CTOPP, and all participants were in grade one upon completion of the task. To examine overall reading and phonological awareness capabilities of participants, means for both PI and NPI groups can be found in Table 3.

Table 1

Participants Frequencies Rhythm Perception

Characteristic		PI (N=28)	NPI (=27)
Sex	Male	16	12
	Female	20	22
Age		6.2 (0.8)	6.0 (0.7)
WJ3 Word Identification SS		94.0 (12.9)	108.4 (16.9)
WJ3 Word Attack SS		94.4 (11.8)	106.9 (13.4)
CTOPP Composite SS		73.3 (8.6)	97.7 (11.4)

Tasks

Phonological Processing. Comprehensive Tests of Phonological Processing, Second Edition (CTOPP2; Wagner, Torgesen, Reachotte & Pearsons 2013)

The Comprehensive Test of Phonological Processing, Second Edition (CTOPP2; Wagner, Torgesen, Reachotte & Pearsons 2013) was used to get a base line of phonological awareness from each participant. During the administration of the test students were asked by the examiner to complete a series of seven subtests that, when brought together, represent one composite score of phonological awareness. The subtests illustrated below, highlight the specifics of what type of subtest was administered, along with the average internal consistency of each subtest. General descriptions of the CTOPP2 were adapted from a review of the test written by Dickens, Meisinger and Tarar (2015). The scores for Elison and Blending words described below were combined to generate a phonological awareness composite, which was then converted to a norm-referenced standard score, as per the CTOPP2 manual instructions.

Elision

Participants listened to a word, were asked to repeat the word, and then asked to say the word with a designated sound removed (e.g., “Say dog without the /d/”.). The average internal consistency reliability is over .90

Blending Words

The participant listened to a series of audio-recorded separate sounds, and was then asked to blend the sounds together to make a whole word (e.g., “What do these sounds make: b-oi?” The correct response was “boy”.) The average internal consistency reliability exceeds .90.

Rhythm Perception Task

This task represented an adaptation of a task used in a previous study. (see Huss, Verney, Fosker, Mead and Goswami, 2011). The current task was adapted to accommodate the appropriate developmental abilities of participants in the present study.

During the task, children were instructed by an administrator that they were about to play a game with two musical dinosaurs. The children were told by the administrator that both of these dinosaurs love to play the xylophone, and that the dinosaurs always love playing the same songs together. The administrator then explained that these dinosaurs like to fool whoever is listening to them play, and that sometimes these two dinosaurs play different songs to try and trick whoever is listening. Subsequently, the researcher asked the child for their help in determining if the songs the dinosaurs played were the same or different. When the child agreed to help they participated in the task pre-loaded onto a computer.

The researcher then told the child to watch the screen for the cartoon dinosaurs and listen carefully to the songs that each of them played. They explained that when both dinosaurs finished their songs, that the child would see a green check mark appear on the screen as well as a red "X". They were then instructed to press the green checkmark if they believed the dinosaurs had played the same song or select the red "X" if they thought the dinosaurs had played two different songs. Once the child completed all the trials, their data was collected and saved.

The task was comprised of 24 total trials. Each trial contained varying rhythms and musical conditions, with each arrangement having a pulse rate of 120 beats per minute (bpm). During half the trials the child heard the same series of notes, while during the other half of the trials they will hear two different series of notes (see Figure 1.). Each child heard 12 trials where the songs were the same, and 12 trials where the notes played were different.

Trials consisted of differing conditions to test perception and response accuracy of participants. Each condition varied in number of notes and or beats, note accents, duration length and the presence of a crochet note. A crochet note can be defined as a musical notation where the delivery of the note also receives one beat. Durations differed in one of three ways: seven trials delivered an accented note at 100 milliseconds (ms); 5 delivered an accented note at 166 milliseconds; and the remaining twelve had no difference in duration. In trials where the notes were different, the participant experienced an auditory stimulus where the trials contained either 2 notes, 3 notes, 4 notes or 5 notes per bar.

Beats per bar differed, where 10 trials had only 3 beats, and 14 trials had 4 beats, and conditions where there was the presence of a crochet note; performance was examined in cases where a crochet note is played, or not played, in the musical pairs. The final distinguishing variable was whether or not the duration change followed a long or short note. In this study, participants heard half the trials with a duration change that followed a long note, and half the followed a short note. Each trial was presented to the child in random order to avoid the child predicting their responses.

The goal of this task was to test if there is a significant difference between correct responses in children who were identified as poor phonological processors, and children whose phonological processing was at a developmentally appropriate level. The varying conditions were present across all 12 trials, and performance was examined based on correct responses within the varying rhythm conditions not the individual trials themselves.

Figure 1. Musical Notations of Varying Trial Conditions

wav 044

wav 054

wav 058

wav 062

wav 066

wav 070

Figure 1. Musical notation containing the varying conditions on musical pairs of “different” trials used in the rhythm perception task. Reprinted from “Perception of Patterns of Musical Beat Distribution in Phonological Developmental Dyslexia: Significant longitudinal relations with word reading and reading comprehension,” by U. Goswami, M. Huss, N. Mead, T. Fosker, and J. P. Verney, 2013, *Cortex 49,* 1368-1369. Copyright 2011 Huss et al. (2011).

Rhythm Reproduction Task

This task was comprised of rhythmic entrainment sequences presented in one trial. The trial contained varying paced conditions chosen to impact the tapping performance for the participant when cued or not cued by an audio stimulus. Over the course of the audio stimuli four different rhythm based conditions were manipulated. During each phase, the rate of tapping, and audio cue were impacted. In phase one participants were entrained to the sequential audio cue that had an inter tap interval (ITI) of 500.0 milliseconds; during phase two, the audio cue remained and the ITI was increased to 666.7 milliseconds. In phase three, the cue was removed and children were required to maintain their tapping rate at an ITI of 666.7ms. Finally, in phase 4, participants heard the audio cue return to an ITI of 500ms and had to adjust, and match their tapping to the stimuli. During the task the child saw a drum on screen and heard a drum beat sound, which cued the suggested rate of tapping. Each participant was intended to follow along to the beat by tapping their finger on a drum they saw on the tablet screen.

While engaging in this task participants were instructed by the administrator to respond to the drum rhythm they heard through the speaker, by tapping on the screen of the tablet using their finger. They were asked to follow this rhythm twice, once as practice and once as an ordinary exercise. They were told by the researcher that the rhythm can sometimes be fast and sometimes be slow. Once the child was briefed on how to complete the task, they were instructed by the researcher to touch the “Play Rhythm” button on the tablet to first begin a practice test to account for the learning curve in participation. A rhythm would then begin playing a sequence of beats and the child was required to copy the sequence. Once the practice trail was complete, the child was asked to stop. They were informed that they could try again, during the ordinary test.

Once the child stated they were ready they selected the “Start Test” button and commenced tapping when they heard the audio cue.

The same instructions and tasks were repeated for each participant during the test phase of the task. The difference in the test phase was that during the trail the audio cue was removed. In this instance, the research encouraged the participant to continue tapping even without the audio cue. To account for the learning curve of the task, only the middle fifteen taps were analyzed for performance over the four phases.

The goal of this task was to test if there was a correlation between how successful a child was at maintaining a rhythm through tapping in conditions where the ITI was increased and in conditions where the audio cue had been removed, and compared performance results to the participants overall phonological awareness scores and determine whether a correlation exists.

Results

Rhythm Perception

Data for the rhythm perception task was explored within each group separately to determine if assumptions of normality were met. The Statistical Package for Social Sciences (SPSS) was used to determine outliers within the samples. For the analysis of the rhythm perception task, any child who did not complete the full set of trials or received score of zero was removed from data analysis. Fifteen participants were excluded for not meeting these requirements. When the removed participants were compared with those who had complete and analyzable data, there were no significant differences between these two groups on age, grade, or average scores on the CTOPP.

Homogeneity of variance assumptions were met, and no post hoc analyses were required, as within group analyse were only between two levels for each condition. Means for the performance between groups on the auditory perception task can be reviewed in Table 2. MANOVAs, with repeated measures, were conducted on the six conditions to compare the effects of the differing musical variables on grade ones who were phonologically impaired. The six within subjects conditions were as follows: 1) three vs. four beats per bar; 2) Noted per bar of 2, 3, 4 and 5 3) duration change of 0, 100 or 166 milliseconds; 4) Metre Change following a long or short note; 5) Accent on first second or third note; 6) The presence of a crochet note Results for each of the six MANOVAs are reported below. There was a statistically significant difference between condition and phonological impairment for conditions containing 2 levels. F (4, 50)=4.09, p=.006; Wilk's Λ= 0.754, η2=.25.

Beats per bar

The first MANOVA, with repeated measures, had number of beats per bar as the within-subject factor and phonological impairment group as the between-subjects factor. The within-subject factor contained two levels, 3 beats per bar and 4 beats per bar; the between subjects factor also contained 2 levels, phonological impaired (PI) and not phonologically impaired (NPI) measured at school start. There were marginal effects of beats per bar, $F(1, 53) = 3.53$, $p = .066$, $\eta p^2 = .062$. and phonological impairment $F(1,53) = 3.03$, $p =.088$, $\eta p^2 =.054$. These effects were qualified by a significant interaction between beats per bar and phonological impairment $F(1,53) = 6.17$, $p = .016$, $\eta p^2 = .104$. There was no difference reported between phonologically impaired participants (M= .53, 95% CI [.47, .60]) and the control group (M= .52, 95% CI [.46, .59]) when there were 4 beats per bar; in contrast, when there were 3 beats per bar, the PI group (M= .51, 95% CI [.46, .57])

Table 2

Means of Group Performance on Rhythm Perception Task

Group	PI *(N=28)*	*(SD)*	NPI controls *(N=27)*	*(SD)*
3 beats per bar *(max=10)*	0.52	*0.15*	0.64	*0.13*
4 beats per bar *(max= 14)*	0.53	*0.15*	0.52	*0.18*
2 /3note sequence *(max=12)*	0.92	*0.30*	1.21	*0.30*
4/5 note sequence *(max=12)*	1.20	*0.35*	1.06	*0.43*
crochet only trial no *(max=12)*	0.45	*0.14*	0.57	*0.15*
crochet only trial yes *(max=12)*	0.60	*0.15*	0.58	*0.17*
No Duration Change *(max=12)*	0.60	*0.16*	0.58	*0.17*
Yes Duration Change	0.80	*0.44*	0.96	*0.47*

(max=12)				
Meter change does not follow long note (*max=12)*	0.60	*0.16*	0.58	*0.17*
Meter change follows long note (*max=12)*	0.50	*0.13*	0.56	*0.16*
Accent on 1st note	0.48	*0.16*	0.58	*0.20*
Accent on 2nd note *(max=12)*	0.54	*0.14*	0.57	*0.14*
Accent on 3rd note *(max=4)*	0.56	*0.23*	0.56	*0.30*

Note: Participants who scored <=85 on the Comprehensive Test of Phonological Awareness at the beginning of grade one made up the test group PI. Participants who scored >85 made up the control group NPI.

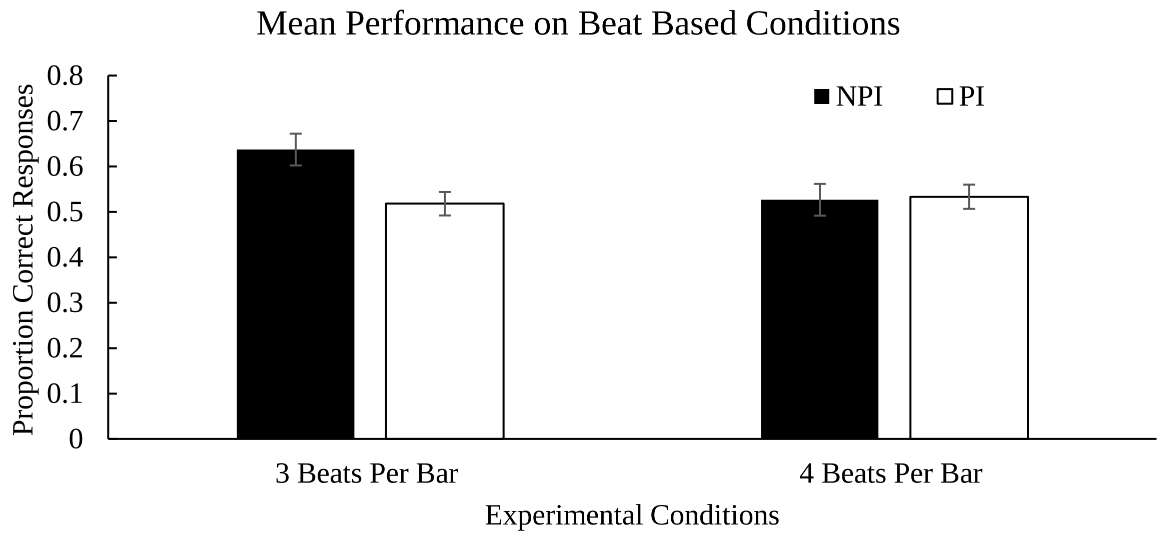

Figure 2. Overall performance between PI and NPI groups on beat perception condition. Where by PI group performed significantly more poorly than NPI group

had fewer correct responses than NPI (M= .64, 95% CI [.58, .69]) see Figure 2. These results indicate that in trials where there were fewer beats per bar, phonological impairment impacted performance on the task. Specifically, participants who were identified as having low phonologically awareness had fewer correct responses, on trials containing less beats per bar; for participants without phonological impairment, rhythms with fewer beats per bar led to an increased ability to discriminate rhythms, with the potential that four beats per bar was just harder for everyone.

Notes Per Bar

Within subject conditions analyzing the impacts of notes per bar on subjects' performance, a MANOVA with repeated measures was used to analyze data. Two levels were used to review the within-subject factor of 2 and 3 notes per bar and 4 and 5 notes per bar; the between subject factor were the PI and NPI groups. No effects were identified on notes per bar, F (1,53) = 1.07, $p = .305$, ηp^2 = .020, and in phonological impairment, F(1,53) = 1.28, p = .263, ηp^2 = .024, but a significant interaction was noted between phonological impairment and beats per bar F(1,53) = 11.69, $p = .001$.

In this instance there was no significant difference found in conditions where there were 4 and 5 notes per bar. Specifically, there was no difference in performance between the PI (*M*= 1.2, 95% CI [1.04, 1.35]) and NPI groups (*M*= 1.06, 95% CI [.91, 1.22]) Notably, when there were 2 and 3 notes per bar within trials, a significant difference between the PI (*M*= .92, 95% CI [.82, 1.03]) group and NPI group (*M*= 1.21, 95% CI [1.1, 1.32]) demonstrated that in cases where there were fewer notes per bar, phonological impairment impacted task performance (see Figure 3). It should be noted that these results indicate that, in cases where there were fewer notes per bar, phonologically impaired participants had fewer correct responses.

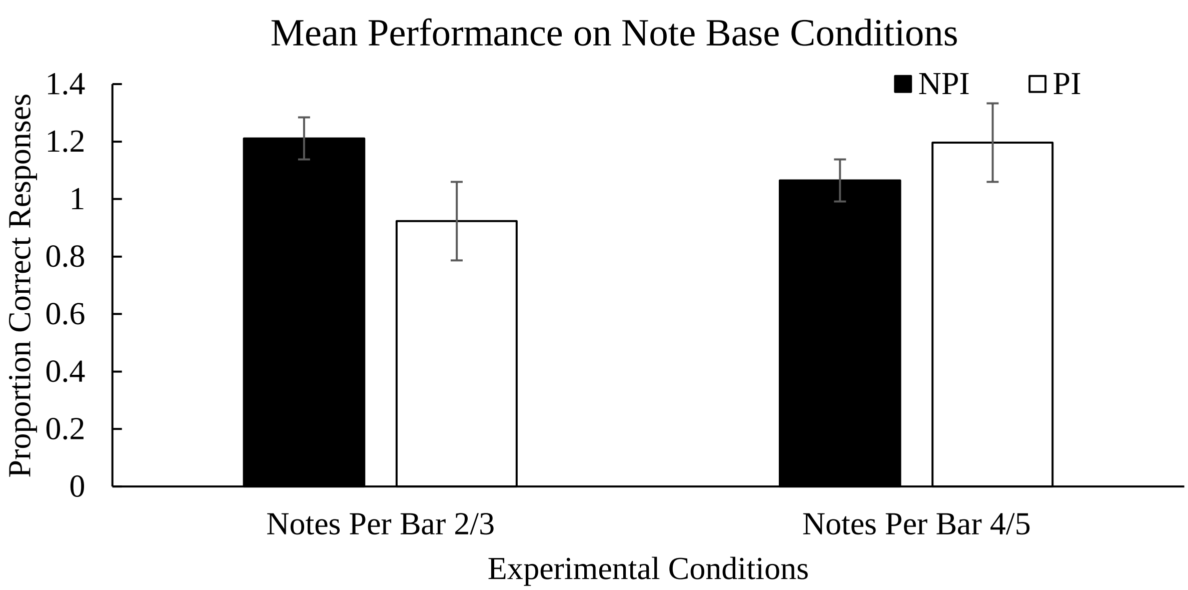

Figure 3. Group performance on Notes per Bar condition. PI group performance significantly more poorly than NPI group.

Crochet Trials

For trial containing a crochet (also commonly known as a quarter note) a, repeated measures mixed MANOVA design was performed to analyze participant performance in trials containing this condition. Again, two variable levels were used to identify performance results between groups. Analysis reviewed the within group impact of trials containing a crochet note, and trials that did not contain a crochet note and the between subjects factor of PI and NPI. Significant effects were identified within the crochet trail condition, $F(1,53) = 10.51$, $p = .002$, $\eta p^2 = .17$ but not in phonological impairment $F(1,53) = 1.90$, $p = .174$, $\eta p^2 = 0.04$. However, a significant interaction between phonological impairment and the crochet trail condition was noted, $F(1,53) = 8.19$, $p = .006$, $\eta p^2 = .134$ indicating that phonological impairment impacted performance on crochet trials.

Specifically, this interaction occurred in trials that did not contain crochet notes. Whereby PI participants (M= .45, 95% CI [.40, .51]) had fewer correct responses than NPI participants (M= .57, 95% CI [.51, .62]) on trials where there was no crochet note present. When reviewing the results for trials that did contain crochet notes, there were no significant difference in performance between the PI (M= .61, 95% CI [.54, .66]) and NPI (M= .58, 95% CI [.51, .64]) groups, see Figure 4.

Duration Change

For trials reviewing the impact of a duration change in the trial and participant performance, a repeated MANOVA was performed. Within group factors represented to levels trials containing a duration change and trials that do not. Between group factors remained the PI and NPI participant groups. Analysis on within group factors noted a

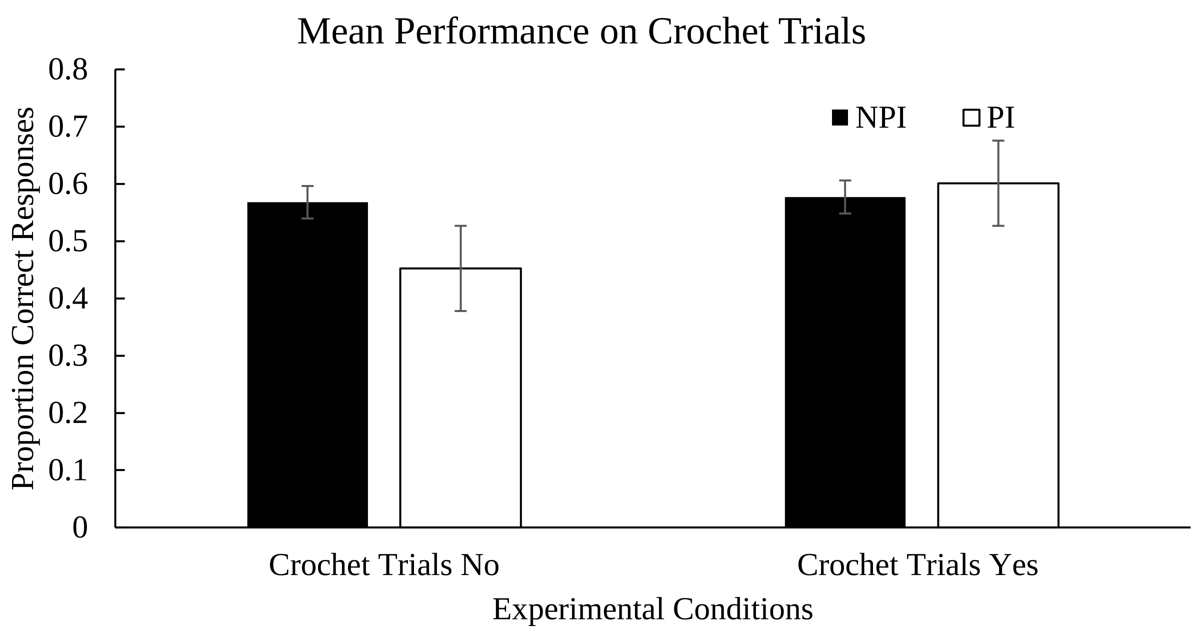

Figure 4. Bar graph of mean performance on crochet trail conditions. This illustrates that PI participants performed more poorly on trials without crocheted notes than with.

significant difference on the duration change condition $F(1,53) = 6.407$, $p = .014$, $\eta p^2 = 0.11$, but none on the between groups $F(1,53) = 2.42$, $p = .126$, $\eta p^2 = .04$. Similarly, no significant results were noted between the duration change trials and phonological impairment $F(1,53) = 1.65$, $p = .204$, $\eta p^2 = .03$. This suggests that duration change within the trial did not impact participant performance on the task.

There were no significant differences in correct responses between the PI group and NPI group on trials with a duration change, and no significant differences between groups on trial without a duration change suggesting that in trials where duration change was a factor, phonological impairment did not impact performance.

Metre Change

A repeated measures MANOVA was performed to interpret the impact of meter change and phonological impairment. Within-group measures represented trials containing a meter change after a long note and trials where the meter change did not follow a long note. Between groups measures remained the PI and NPI participants. Upon analyzing the within group factors, a significant result was noted for the meter change condition $F(1,53) = 6.50$, $p = .014$, $\eta p^2 = .11$. Between subject effects noted no significant interaction between groups $F(1,53) = 1.90$, $p = .174$, $\eta p^2 = .04$. when comparing meter change and phonological impairment results approached significant results $F(1,53) = 3.76$, $p = .058$, $\eta p^2 = .07$ but indicate that meter change was not significantly impacted by phonological impairment.

No significant results were found when reviewing group performance and meter change conditions within the trials. In cases where trials had a meter change following a long note, there was no difference in performance between PI and NPI groups. Similarly, on conditions where meter change did not follow a long note, and groups showed no difference in performance.

Accented Note

For the final condition reviewed results of where notes were accented within the audio cue in each trail were analyzed for to determine if phonological impairment had an impact on performance of trials containing these conditions. A MANOVA, with repeated measures, was used to measure the significance of this relationship. Within groups variables had three levels, notes within the trials were accented either on the first, second or third note. Overall this represented the accented note conditions. The between groups remained the PI and NPI test groups. Within group factors did not show a significant relationship, $F(2, 106) = .54$, $p = .586$, $\eta p^2 = .01$, similarly between group factors were all not significant, $F(1, 53) = 1.08$, $p = .304$, $\eta p^2 = .02$. Finally, when reviewing the relationship between phonological impairment and accent note, no significant results were identified, $F(2, 106) = 1.22$, $p = .300$, $\eta p^2 = .02$.

Rhythm Reproduction Task

For the rhythm reproduction task median participant performance, within both groups, were analyzed to cope with the non-normality of the data. Mean tapping accuracy across 15 trials was positively skewed. As a result, median tapping accuracy was taken across the full set of trials for each phase of the rhythm production task. In the case of this study, any child who did not complete the full set of tapping tasks, and or missed one or more sections of the task were removed from data analysis. In the case of the rhythm reproduction and entrainment task, 3 participants were excluded for not meeting those requirements. During analysis of the group, the 3 removed participants did not differ in average age, grade or score on the CTOPP.

Homogeneity of variance assumptions were met, and post-hoc tests on the between-subject factors were not required as within group analysis was between 2 levels. Overall tapping performance between both the PI and NPI groups can be reviewed in Figure 5. An ANOVA design, with task phase as a repeated measures factor, and phonological impairment group, was carried out for the rhythm task and the results are noted below.

When analysis was repeated to include early reading measures for letter word identification and word attack, using the same repeated measures MANOVA, the results illustrates above remained significant with the exception of the beats per bar condition.

Rhythm Entrainment Performance Overall

During the rhythm entrainment task, participants were exposed to 4 phases of a single rhythm. When performing the ANOVA with repeated measures, within subject conditions were all 4 differing phases of the rhythm task, and the between subjects represented the PI and NPI groups. To begin, overall results showed that within subject differences were significant, $F(3,195) = 32.54$, $p = <.001$, $\eta p^2 = .334$ and between subject effects also showed significant results, $F(1,65) = 9.90$, $p = <.001$, $\eta p^2 = .13$. The interaction between phase and PI was also significant, $F(3,195) = 3.42$, $p = .02$, $\eta p^2 = .05$, indicating that phonological impairment groups differed in their tapping ability by phase, see Figure 6.

The Impact of Rhythm Cue and Pace Between Phases. Pairwise comparison for the main effect of Rhythm Phase, corrected for Bonferroni adjustments, are highlighted in the Table 3 below. The table indicates that significant main effects, between phonological impairment and phase, are based on the change in rhythm between phases. Specifically, the change in ITI from each phase of the entrainment task and the presence or removal of an audio cue during the task for the participant. In this case, significant results were noted whenever there was a transition between phases. For example change in the presence of an audio cue heard by the participant, or transition when the rate of tapping increased from 500ms to 666.7ms. seemed to impact performance for significantly for PI participants. Notably, significant group differences were found between phases 1 and 2, 1 and 4, 2 and 3, 3 and 4, but not between 1 and 3 or 2 and 4.

Highlighting that in each significant phase, the transition from one ITI from 500ms to 666.7ms is when performance between PI and NPI groups dropped, regardless if there was an audio cue present. This occurred specifically from phases 1 to 2, and 1 to 4. Generally, in any phase where participants were tapping at a higher rate, both groups struggled to increase their rate of tapping, PI groups failed to tap at the cued faster or slower rate than the NPI groups, see

Figure 5. Further indication of the impact of tapping rate was noted by the lack of significant group differences in phases where tapping rates were the same. Largely, performance between the two groups during the phases where the rhythm pace was at an ITI of 666.7, showed a distinct difference in performance between groups. In phase 1 the PI group performed significantly more poorly (*M*= 449.61, 95% CI [426.54, 472.68]) than the NPI group (*M*= 472.28, 95% CI [447.81, 496.75]) compared to performances on phase 2; PI (*M*= 535.53, 95% CI [494.66, 576.40]) NPI (*M*= 621.41, 95% CI [578.06, 664.75]) See Figure 6.

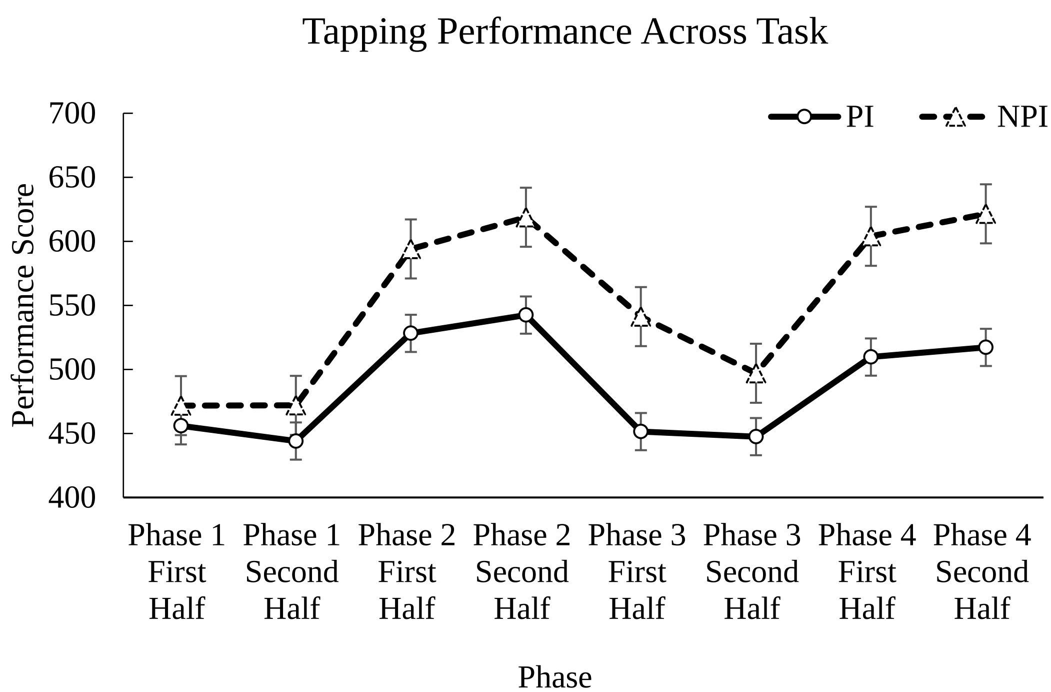

Figure 5. Line graph of median performance across Rhythm Entrainment task. This illustrates similar performance between PI and NPI groups, with significant difference in performance between PI group and NPI group in phases 1 and 2, 1 and 4, 2 and 3 and 3 and 4.

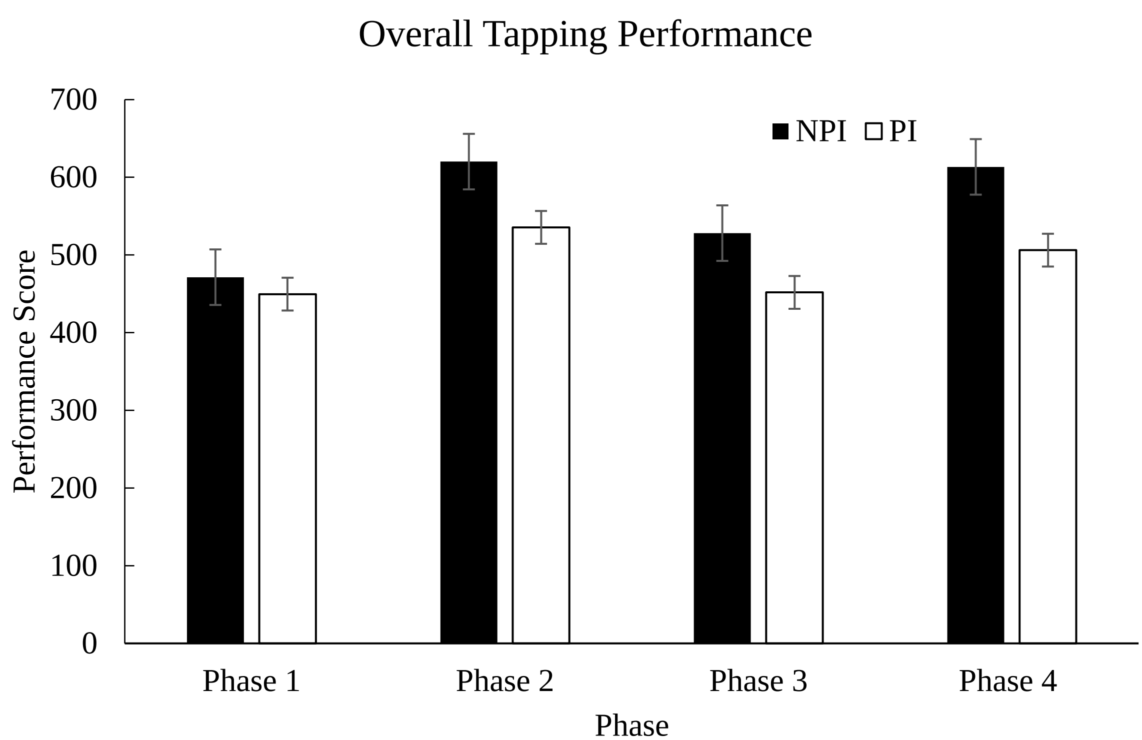

Figure 6. Clustered Bar Chart demonstrating the tapping performance of PI and NPI groups across Rhythm Entrainment Task. Notable differences can be seen in Phase 2, 3 and 4.

Table 3.

Pairwise Comparison for Main Effect of Rhythm Phase

(I)phase	(J) phase	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-117.362*	13.531	.000	-154.185	-80.538
	3	-29.489	15.339	.354	-71.234	12.256
	4	-99.307*	15.879	.000	-142.521	-56.093
2	1	117.362*	13.531	.000	80.538	154.185
	3	87.873*	13.601	.000	50.860	124.885
	4	18.055	10.384	.521	-10.204	46.313
3	1	29.489	15.339	.354	-12.256	71.234
	2	-87.873*	13.601	.000	-124.885	-50.860
	4	-69.818*	13.672	.000	-107.025	-32.610
4	1	99.307*	15.879	.000	56.093	142.521
	2	-18.055	10.384	.521	-46.313	10.204
	3	-69.818	13.627	.000	32.610	107.025

Note. Rhythm phased performance was determined based upon the difference value between the ITI.

Beyond just tapping rate, the presence of an audio cue also impacted performance between groups. Between phases 2 and 3, when the audio cue was removed but the ITI remained at 666.7ms, both group's performance dropped, but a significant between group differences were noted from phase 2 to 3; whereby the PI group struggled to maintain the correct ITI at a higher rate without an audio cue. Similarly, the return of the audio cue could explain the significant group differences between phase 3 and 4. In this case, the PI participants again had a poorer performance (*M*= 451.85, 95% CI [406.66, 497.03]) than the NPI group (*M*= 511.63, 95% CI [463.70, 559 .55]) between phase 3 and phase 4; PI (*M*= 506.21, 95% CI [459.72, 552.70]) NPI (*M*= 614.80, 95% CI [565.49, 664.11]) when they had to match their perceived tapping to the actual rhythm when it returned. Although the ITI was the same between both phases, the removal of the audio cue in phase 3 was enough to throw off performance in phase 4. This suggests that PI participants struggled to modify their tapping rate back to an ITI of 666.7ms when reminded by the return of the audio cue, at more significant rate than the NPI group when the audio cue returned. This result suggests that changes in audio cue and the presences of phonological impairment had an impact on task performance. Means of overall performance between PI and NPI groups, in each phase, can be reviewed in Table 4 below.

Although change in ITI and audio presence demonstrated significant groups differences across many phases, certain between phase difference was not indicated as significant even if there was a conditional difference in ITI or the presence of an audio cue. Performance between phase 1 and 3 showed no significant group difference, and similarly, no group difference was seen between phase 2 and 4. Noting again that transitional phases were more impactful on performance.

Taken as a whole, what these results indicate is that in cases where participants had phonological impairments, children struggled to maintain their tapping rate when the ITI increased, and underperformed compared to the control group when the audio cue was removed during the task, indicating that changes to rates of tapping, and predicting the rate of tapping when there is no audio cue are all impacted by the presence of a phonological impairment in a participant.

Table 4

Group Performance on Rhythm Entrainment Task

Phase *(ITI)*	PI (N=36)	*(SD)*	NPI (N=31)	*(SD)**
1*(500.0ms)*	449.61	*(75.25)*	471.39	*(62.80)*
2*(666.7ms)*	535.53	*(151.58)*	620.20	*(79.56)*
3*(666.7ms)*	451.85	*(126.65)*	528.13	*(113.33)*
4*(666.7ms)*	506.21	*(160.54)*	613.40	*(113.16)*

Note. Participants who scored <=85 on the Comprehensive Test of Phonological Awareness at the beginning of grade one made up the test group PI. Participants who scored >85 made up the control group NPI.

*Large standard deviations are a result of high variance of ITI within the rhythm production task for both participant groups

Discussion

The central questions driving this study were to examine whether children who are phonologically impaired, would encounter challenges on rhythm based tasks that test children's ability to tap to varying rhythms, as well as, differentiate between changing rhythm conditions when comparing two sound sequences. With the purpose of helping to find a relationship between reading impairment, and neural rhythm processing. Specifically, this study sought to examine three main questions relating to the relationship that rhythm interpretation has to reading and phonological awareness: 1), can using existing methodologies for determining rhythm production and differentiation with grade one students, produce similar results to existing research previously administered in an older population of children? 2), does scoring low on standardized tests for phonological awareness, predict a significant relationship to poor performance on rhythm production, and differentiation tasks similar to the relationship identified between reading and rhythm? 3) are there specific rhythmic variables within audio cues that highlight rhythm interpretation and response to changes as the key variable over others where participant performance is negatively impacted? Overall results from data analysis demonstrated that each of the research questions posed in this study are supported by significant interactions in the results of the experimental tasks.

Rhythm Differentiation

When looking at the capacity in which phonologically impaired children have for differentiating rhythms, this study found that in instances where there were lower rates of complexity between musical cues, children who were phonologically impaired at the beginning of grade 1 struggled more, at correctly identifying musical sequences, than participants who were not phonologically impaired. This appeared to occur in cases where the musical cue contained fewer notes, different note lengths, and fewer beats. These findings suggested that when considering if there are specific types of rhythm based variables, that impacted performance on participants when differentiating between audio cues, overall changes made to rhythm based variables showed poorer performance for children who scored lower on the test for phonological awareness, in comparison to, those who scored above 85. For example, when rhythmic variables such as number of notes were different between pairs, children struggled making a distinction, then when asked to differentiate between other pairs of impacted rhythm variables. In cases where musical meter was changed after long or short notes, ability to differentiate between audio pairs was not significantly impacted by phonological awareness. Although rhythm in both cases was impacted, there was a notable difference in musical complexity between the variables, and results seem to suggest that this complexity of the rhythmic variables within the audio cue may have impacted performance.

Study outcomes supported the idea that when there is higher rhythm complexity in a sequence played to a participant with phonological impairment, participants had an easier time differentiating between an audio cue, than in cases where there was less complexity in the audio cue. Interestingly, when there was less manipulation to rhythmic variables within an audio cue, it was harder for phonologically impaired children to tell the difference between correct and incorrect pairs. Significant results suggested, that in cases where there were fewer notes per bar, children who were phonologically impaired had a harder time distinguishing different pairs. When looking at pairs with more notes per bar, participants had an easier time distinguishing pairs as same or different. Again demonstrating that when rhythm pairs were complex in amount of rhythm based variables it was easier to distinguish for low phonologically aware children, compared to pairs with subtler and smaller number of changes to number of notes and beats.

There is a case to suggest that any rhythmic variable that altered rhythm complexity would significant differences between study groups, but the results also noted that some variables were more impactful on participant's ability to differentiate than others.

Although it appeared that specific rhythm sequences with less complexity were harder to differentiate for phonologically impaired participants, this only related to certain rhythm variables in the audio cue. If there were two or three notes present, participants struggled more than if there were four or five notes present. With audio conditions where there were three beats present instead of four, phonologically impaired participants had fewer correct responses than participants who were not phonologically impaired. In trials that contained a crochet (quarter) note phonologically impaired participants' performance did not significantly differ than non phonologically impaired participants. This may indicate that differences such as a crochet note may be too subtle for any participant to pick up, and in the case of the participants in this study changes to crochet notes went reasonably undetected in both groups.

The issue of complexity in these conditions was specifically focused on notes, beats and the presence of a crocheted note. More significant and noticeable changes in rhythm. Not all conditions that would alter the complexity of the rhythm sequence resulted in a significant difference in performance. In audio cues containing notes that were accented, a difference in the duration of the rhythm, and if a musical meter change followed a long or short note, no significant difference was found in performance. In these cases, again, the changes to the rhythm structure were so subtle they may have gone undetected by both groups of participants.

The importance of these results, are that they seem to support the idea that there is indication of a specific connection to the neural processes involved with interpreting an audio rhythmic stimuli. Specifically, in relation to processing changes in major rhythmic variables, suggesting that when there is a problem differentiating between lower complexity sounds, children who have low phonological awareness may constantly struggle with making a distinction.

In regards to the research questions posed by this study, the differentiation task does seem to provide supporting evidence that indicates a relationship between rhythm and phonological awareness. Specifically, the results of this task did demonstrate that when changes to rhythmic variables were made, phonological awareness appeared to be linked to performance.

As noted in the results, the question of whether there are specific rhythm variables that impact performance on the differentiation task seemed to indicate that beats per bar and notes per bar had a more significant impact on performance than meter change or accented notes, suggesting that the processing of specific changes to rhythm may impact performance more than others. Finally, just as in the previous studies using similar methodologies, the results of the differentiation task noted that poor performance on phonological awareness tasks seemed to result in lower performance when differentiating musical pairings with different rhythmic variables. These similar results to previous research, support the validity of these types of tasks when examining the relationship between phonological awareness and rhythm interpretation.

Outside of this study, other authors have examined the performance on rhythm tasks and reading and similar results have also been noted, Specifically, two studies similar in methodologies and variables reviewed, had similar findings in certain rhythm conditions. One study in particular, was performed by Goswami et al. (2013), where the authors examined how children with an assessed reading impairment performed on rhythm differentiation task, and also determined that in cases where there were 3 beats, and no crocheted notes present, that participants who were identified has having reading challenges, performed significantly more poorly than the standard reading control group. In the case of this study participants varied in age, and were specifically identified for their phonological impairment instead of reading, but with the established connection between phonological impairment and reading, associations can be drawn between the similar results of this study and the findings of Goswami et al. (2013). Comparable results between reading and rhythm processing can be found, in research conducted by Huss et al, (2011). In this case, the examiners set out to find a connection between reading ability and rhythm perception. Huss et al. (2011) examined an equivalent hypothesis of reading and rhythm processing, between poor readers and typically developed readers, whereby participants were to select if the rhythms presented in a pair sequence, were the same or different. Conditions in the Huss et al. (2011) study matched the conditions in this current study. Both examined 3 and 4 beat sequences, quarter notes, accented notes, and duration. Huss identified that significant relationships occurred between poor readers and standard readers in performance on rhythm sequences that contained 3 beats, and crocheted notes. As noted, these results matched the results of this present study, and added support to the connection between the role rhythm processing plays in later reading development.

Within the rhythm differentiation task, participants differed from the above mentioned studies in that the poor reader variable was substituted out for a phonologically impaired variable in the sample groups; to account for the difference in age and present reading levels of participants in this study. Given that the average age and grade of the participants being six years old, and phonologically impaired at the beginning of grade one, the performance on phonological impairment tasks better suited the organization of the samples so that they represented children who could possibly be identified with reading challenges in the future. Although the sample variable differed in the connection between phonologically impairment and reading, results remained consistent, and suggested that just as a reading impaired group would have fewer correct responses, so did groups who were identified as phonologically impaired.

Alternative explanations to the results found in this task could be identified by reviewing research into parallels between phonological impairment and attention, although previous investigations as stated earlier, has supported similar findings as the ones in this present study. Literature does exist that supports a connection to auditory attention and specific learning disorders that could also explain the results of this study (Victorino & Shwartz, 2015). But, based on examining auditory attention problems, it would be expected that phonologically impaired participants would show significant differences in all varying audio conditions, not just the unique varying rhythm conditions as was noted in the results of this study. Similarly auditory memory and its relationship to phonological awareness should be examined more deeply in relation to theses tasks to examine if it has a role in the relationships found within this study.

Rhythm Reproduction

Similarly to the results found in the rhythm differentiation task, significant group differences were noted between phonologically impaired participants and non-phonologically impaired participants, in rhythm tasks focused on the entrainment of a rhythm sequence. When tapping to the beat of an audio cue, children who scored lower on phonological awareness tests struggled to regulate their tapping to changes made in rhythm pace, as the audio cue moved between different phases. In the case of this present study, children who were phonologically impaired at the beginning of grade one performed more poorly when asked to match their finger tapping to a rhythmic audio cue varying in different rhythm conditions, specifically focused on the presence of sound and pace of the audio cue.

In both groups, results indicated that phonologically impaired participants, and non-phonologically impaired participants, followed similar tapping patterns throughout the differing rhythm conditions. In cases where rhythm sped up between phases performance dropped, and also in cases where the audio cue was removed performance between both groups dropped. Where significant differences were noted, was in the capacity to adjust tapping to differing rhythm conditions, specifically in cases where the rate of tapping increased from 500ms to 666.7ms. Across the task, in most transitional phases, where the rate of tapping increased, phonologically impaired participants failed to up take the new rate of tapping more poorly than the non-phonologically impaired participants.

Additionally, the removal of the audio cue for the participant increased the difference between each group. A significant gap in performance between the groups occurred during the phase where the rate of tapping remained at 666.7ms, but the audio cue alerting participants of the pace was removed. Both participants struggled to maintain their tapping rhythm with the removal of the audio cue, but in the case of students who were phonologically impaired, their rate of tapping differed from the average tapping rate of non-phonologically impaired participants significantly, and this carried into the final phase where the audio cue returned. Phonologically impaired participants, although having tapped in the same condition earlier in the task, could not adjust back to a consistent tapping performance in the final phase of the rhythm, when compared to the control group.

In relation to the research questions asked by this study, results found by the rhythm entrainment task demonstrated supporting evidence that endorsed predictions made by the hypothesis of this study. When considering the impact of change to specific rhythmic variables on task performance, it was the failure by phonologically impaired participants to uptake changes in rhythmic tempo of the audio cue, that seemed to be a challenge when moving through the variables of the task. Specifically, as stated earlier, the significant difference was identified that when the tapping cue increased in rate between phases, phonologically impaired children's performance was impacted more than children in the control group. This change in performance was also noted during the entrainment task when the audio cue was removed. There are significant between group differences in performance when the rhythmic cue was removed for participants. Its notable that all participants seemed to struggle to maintain a beat when the cue was removed. The major difference is that the lack of a cue, and then its subsequent return during a later phase had a larger impact on the proper tapping rate of phonologically impaired children. The loss of the audio cue and then its return, was enough to negatively impact the overall performance of phonologically impaired children for the rest of the task. Suggesting that just as with the differentiation task, changes made to specific rhythmic variables in the audio cue negatively impacted task performance for children who had low phonological awareness, providing evidence that this study supports the research questions being examined.

Past research administering similar tasks have also noted similar significant results with older children. Highlighting support for the question as to whether or not similar results can be found in a study on younger children. In one experiment specifically, Thomson (2008) found that in the case of 10 year olds identified as having dyslexia, participants could not synchronise their tapping to an audio cue as well as participants who were typical readers. Additionally, a study also conducted by Couriveau and Goswami (2009), examined variations of paced tapping conditions between children ages seven to eleven, with specific learning impairments, and typically developed learners. The authors noted significant between group differences on rhythm production tasks similar to the results found in this study. A notable difference between this current study and the Couriveau and Goswami (2009) is that in the case where the audio stimulus was removed from the rhythm sequence, the participants in this study showed significant groups differences, but not in the Couriveau and Goswami (2009) case. The authors made note that upon removal of the audio cue, task performance for each group was significantly thrown off in both cases, resulting in no significant between-group differences. The methodology of this study, that includes both the removal of the audio cue and the return of the cue after removal, may have been what supported the participants from being able to maintain performance in the tapping task.

The results of this task, are similar to ones found in previous research on older children, are important as they support a specific connection to rhythm based task performance and phonological awareness and reading. Participants who struggle on tasks assessing phonological awareness in grade one, seem more challenged to maintain cued rhythmic tapping rate in comparison to non-phonologically impaired participants, just as in the previous research performed on older participants stated earlier. Additionally, the results of this task highlight a potential connection between the motor reaction to an audio sequence, and phonological impairment; due to the nature of the results demonstrating that in conditions where the rate of tapping increased, phonologically impaired participants could not match the new tapping rate.

With the average age of the participants being 6 years old and the presence of similar significant differences to previously existing studies, it adds evidence to the idea that phonological awareness, literacy, and motor skill performance, for individuals with specific learning disorders, manifest similarly across the lifespan. When the results of this study are compared to similar studies on older participants, it is notable that similar discrepancies were also found in adults when compared to research conducted by Thompson, Fryer, Maltby et al. in

2006. When examining the tapping performance of adults with reading delays, the authors noted that even adults who struggle with reading seem to also significantly struggle to tap to a rhythm, just as the phonologically impaired children of this study. Answering the research question posed by this study, that testing for performance on rhythmic based tasks indicate similar results in younger children has it has for older children, in similar studies.

Alternative explanations to the results of this task could be explained by two differing processing impairments being present in children with phonological impairments, since motor control functions are processed in a different part of the brain, an impairment or processing deficit in this location could also explain between group differences. Future research accounting for motor skill performance, could help generate supportive evidence into the rhythm processing connection and tapping performance being the specific cause when account for no differences on motor skill tasks.

Connecting Differentiation and Tapping Performance

Although this present study analyzed beat perception in musical pairs, separately from the tapping task, similar significant differences between groups, may indicate a unique connection between differentiation and performance. The role of rhythm perception, in the reproduction task may indicate a deeper relationship between perceiving the beat and following the timing physically. The result of this research supports evidence of neural connections between rhythm perception and performance when examining the capacity to perceive and subsequently tap to a rhythm. In previous studies, often it has been unclear whether performance on rhythm perception tasks and the subsequent capacity to tap in time to a rhythmic auditory stimulus could be linked neurologically. Often when examined together beat synchronization and rhythm perception are highlighted as being independent of each other (Sowinski & Dalla Bella, 2013). This idea has also been supported by evidence into rhythm perception and performance being separate in instances where the processes are impacted separately in cases neurological developmental delay and localized brain damage (Grahn, 2012; Repp & Su, 2013).

Interestingly the results of this study suggest that in phonologically impaired groups, both the performance on rhythm perception and rhythm production tasks when following a beat, substantiate the idea that the neural networks supporting rhythm perception and performance may in fact be more linked than previously understood. In the case of this study, children who performed poorly on rhythm perception tasks also performed poorly on rhythm performance tasks. More specifically, on the rhythm reproduction task participants failed to perceive the changes in the rate of the rhythm between task phases and were slower to adapt their tapping rate. The results of this present study also support, and are similar to, a recent study by Bégel, Benoi, Correa, at al. (2017) where the authors examined the performance of self confessed “beat deaf” female university students against typical non musician participants. Results on tasks associated with rhythm perception and performance, when keeping time to a metronome, indicated that “beat deaf” participants’ poor performance on rhythm perception predicted poor performance on rhythm tapping tasks. Specifically, the authors noted that it was the lack of perception in relation to the changes in rhythm between phases that resulted in a poor performance.

The results from Bégel, Benoi, Correa, at al. (2017) and the results of this current study suggest that in order to understand how rhythm processing more specifically operates within the brain, attention must be paid to its dual relationship between perception and the physical action of tapping or moving to the beat in further research.

Limitations

Limitations to this study have been briefly identified while discussing the implications of the results for each rhythm task. Most notably, these results suggested, that for future research to advance the understanding of neural rhythmic processing, and its relationship to reading, the limitations of this study need to be considered.

To begin, one of the challenges this study has is that it only examined the relationship between phonological awareness in grade one students, and participant performance on rhythmic tasks. Although there is evidence to support similar results between studies of older children, the age of the participants in this study limited the capacity to directly suggest that these same result will be found in older participants. Similarly, to age of participants, a limitation of this study includes the number of children who participated. A lower participation rate may have restricted which rhythm variables in both the entrainment, and differentiation task, were significant.

Although this study followed tasks designs based on similar methodologies used in previous research, accommodations to the design were made to suit the developmental needs of younger participants, again limiting the capacity to make a direct link to similar studies performed on older children. To accommodate this, future studies should modify the design to be inclusive of longitudinal data collection, while using the exact design and framework of the rhythm tasks outlined by this study so more direct conclusions could be drawn between older and younger readers.

Results suggested that there is evidence to support a neurological connection in the brain between rhythm processing and phonological awareness, but this study did not actively use methodologies that would identify this neural connection explicitly. The results support previous research and provide evidence of a connection, but cannot specifically identify that there is a connection. To accommodate the lack of direct neurological evidence in this study, between phonological awareness and reading, future studies may wish to use PET scans or other appropriate neurological tests while participants are performing the tasks to see if execution of phonological awareness tasks, and rhythm tasks will highlight the areas of the brain where processing is occurring through further neurological observations.

Other limits to this present study include the number of rhythm tasks present. While this study was able to suggest evidence of a connection between specific rhythmic variables in regards to differentiating rhythms, there are possible other variables that impact rhythm interpretation that could be identified as impactful through the inclusion of more rhythm tasks that examine other variables of rhythm. By only having two tasks present that just reviewed differentiation and entrainment of rhythm, this study could only identify significant relationships based on the specific rhythmic variables used for both the entrainment and differentiation task. Future studies should include tasks that examine other aspects of rhythm to also provide evidence that notes the unique components for rhythm that may be impacting task performance. For example, the design of this study was only able to review performance by comparing test results to the relationship between phonological awareness and rhythm differentiation and entrainment. Based on the design, this study could not make direct conclusions regarding the impact rhythm tasks could have on strengthening phonological awareness or reading ability. It would be critical to continuing reviewing if rhythm or sustained musical practice had a positive impact on the development of reading ability. Using the evidence of this study as support, future research may should include rhythm tasks as identifiers of student intervention, that may flag students for delays in phonological awareness or reading. If these tasks have the potential for improved early identification, and subsequently early intervention, the implications that studies such as this have for the field of teaching and education.

These differences cannot be completely ruled out as an explanation due to some of the limitations found within this study. Primarily, the choice was made to examine the score of phonological processing task and not reading performance tasks. This choice relies on the understanding of the reciprocal relationship between readings and phonological awareness. As a result, it limits the ability to draw complete connections between reading and task performance.

Additionally, a larger sample size, could result in variations in results on rhythm differentiation task performance, and further research into this should seek to grow the sample so to increase the validity of results and reduce the capacity for a Type II error. Finally, limitations in the CTOPP test, could also result in variations in sample groupings. Participants who are on the cusp of achieving a score of 86 could potentially fall into either sample depending on a variety of factors that could impact performance on any given day. If indeed there is a specific connection between performance on tasks relating to phonological impairment and rhythm differentiation, it could be suggested based on the results of this study that as phonological awareness scores increase, so will the amount of correct responses on the differentiation task when conditions impacting the rhythm of the audio cue are present. Future research could use this frame work to help organize new samples of varying scores on the phonological tests where there are low medium and high scores on phonological processing test to help test if there is a positive correlation between phonological impairment and performance on rhythm differentiation tasks.

Finally, limitations to the rhythm entrainment task, are that specific attention was paid to separating the sample groups by phonological awareness, and not by the above mentioned motor skill performance. The addition of other experimental groups as a control for the impact of motor impairment may also help rule out if motor skill performance it directly impacting this relationship. Also, growing the number of participants could help support study validity where by more significant in group difference could be noted.

Implications for Education

With the results of this study indicating a significant relationship between children's ability to process rhythm and their phonological awareness, the significant results could be used as evidence in developing rhythmic tests as tools for identifying early reading delays in conjunction with already established valid testing models. With this study and previous research both indicating a connection between phonological awareness and rhythmic processing, educators may wish to use similar entrainment and differentiation tasks to identify any at risk children in pre-reading grades, so that subsequent interventions can be given to students who score low on comparable tasks. Implications of using rhythmic tasks as earlier identifiers for later reading problems help support the discourse of early interventions with reading delays as being paramount in supporting the learning trajectory of children who struggle with reading.

Similarly, if evidence can be found that demonstrates how tasks such as those used in this study can be used as an early identifier, these tests may be used as pre and post indicators for reading intervention strategies. As stated in the review of literature, and throughout the discussion, studies examining Dyslexic musicians may provide evidence that improvements to performance on rhythm tasks compared to non dyslexic musicians, may indicate evidence of a reciprocal relationship between reading and rhythm perception. Future research may wish to examine if in fact performance on these tasks can be improved through early reading intervention and supports, and additionally, look at the capacity in witch teaching music or rhythm activities may support better phonological awareness and reading.

If this evidence can prove to be consistent over future research, another educational implication of reviewing rhythms relationship to literacy, is that it supports the value of including musical curriculum for students. The removal of funding or lack of focus on arts based curriculum which includes musical instruction, may have larger negative implications for children learning to read. As a result, it would be valuable to conduct this research with an educational lens to test these suggested implications on children in the classroom, for the purpose of developing another way to identify reading disorders early, or new teaching strategies that could support the relationship literacy and rhythm awareness seem to have with one another.

Conclusion

As noted, general results of this study suggest that in cases where grade one children are phonologically impaired, performance on tasks testing the perception and performance of rhythm, may be directly impacted by phonological processing impairment. Specifically, they perform more poorly on tasks testing their rhythm perception and capacity to tap in time to a beat than their non-phonologically impaired classmates. The results of this study continue to support the growing evidence of the connection between the similarities in how the brain processes phonemes and how it processes musical rhythm. With the historical evidence, that there is indeed a connection between phonological awareness and reading, this study also lends support to the idea that performance on rhythm base tasks can help predict later reading success.

The implications of this research and similar research, is that it in instances of early identification of reading disabilities the use of rhythm tasks that test performance or correct responses in distinguishing separate sounds may be viable ways to flag poor readers. Given that the participants in this study represent early readers, rhythm tasks could sever as a viable option for education professionals and practitioners to utilize these tests to identify early or pre-readers as being at risk for specific learning disorders or reading problems, based on their performance on rhythm based tasks.

With results also linking musical entrainment and rhythm perception to phonological awareness and reading. This study further adds to the evidence of a neurological connection between music and rhythm interpretation and reading.

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